Remote-Sensing Retrieval of Oceanic Inherent Optical Properties by Inversion of the Radiative Transfer Equation

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LONG-TERM GOAL

The overall goal of this work was to develop and evaluate a new method of inverting remotely sensed ocean color data to recover the "big three" water inherent optical properties (IOPs), namely the phytoplankton absorption coefficient, the CDOM+detritus absorption coefficient, and the total constituent backscattering coefficient.

OBJECTIVES

Semianalytic radiance models [Gordon et al., 1988; Morel and Gentili, 1996] can be readily inverted by linear matrix methods [Hoge et al., 1999a,b] to provide oceanic inherent optical properties (IOPs). Such inversions are well conditioned [Hoge and Lyon, 1996] and promise a powerful method of simultaneously retrieving constituent absorption and backscattering coefficients in the upper surface layer of the world's oceans using satellite data. However, semianalytic radiance models do not provide an exact framework to account for all possible environmental and viewing conditions [Weidemann et al., 1995].

The radiative transfer equation (RTE) can provide exact inverse solutions, but the RTE is not easily inverted for many remote sensing situations [Zaneveld, 1995]. We therefore investigated the inversion of a specific form of the RTE, namely a modified version of the shape-factor formulation of Zaneveld [1995]. Some of the motivation for this work comes from the distinct need for highly accurate methods to retrieve the absorption coefficients of the chlorophyll accessory pigment phycoerythrin [Hoge et al., 1999b]. To this end the absorption coefficients of chlorophyll and CDOM must be accurately retrieved, otherwise weaker absorbing constituents (such as phycoerythrin) will be obscured.

APPROACH

Given measured water-leaving radiances or remote-sensing reflectances, it is not possible to invert the radiative transfer equation (RTE) to obtain the water column absorption and backscatter coefficients unless additional assumptions are made, or additional information is added, to constrain the inversion. Our approach to constraining the inversion is to model selected unknowns—the so called shape

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14. ABSTRACT

The overall goal of this work was to develop and evaluate a new method of inverting remotely sensed ocean color data to recover the ???big three??? water inherent optical properties (IOPs), namely the phytoplankton absorption coefficient, the CDOM+detritus absorption coefficient, and the total constituent backscattering coefficient.

15. SUBJECT TERMS

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factors and related quantities—as well as possible in terms of known quantities, and then treat the shape factors as known in the inversion process. This reduces the number of unknowns in the inversion, at the expense of introducing uncertainties via the imperfectly modeled shape factors. Clearly, the ultimate success of the inversion depends on how well the shape factors can be modeled.

If IOPs such as the absorption and backscatter coefficients are recovered as part of an iterative inversion algorithm, then the recovered IOPs can be used to model the shape factors because both the recovered IOPs and the IOP-dependent shape factors are iteratively improved during the course of the RTE inversion. In the present modeling, we considered the absorption coefficient a, the beam attenuation coefficient c, and the backscatter coefficient b_b to be the recovered (i.e., known) IOPs.

WORK COMPLETED

A database of Hydrolight-generated synthetic data was generated from a large number of Hydrolight runs using different water IOPs, solar angles, viewing directions, wavelengths, etc. (Hydrolight is described at www.hydrolight.info; see also Mobley, 1994 and Mobley and Sundman, 2001a,b.) Each record in the database (184,800 in all) contained the input IOPs, solar angle, etc, as well as the corresponding shape factors and the water-leaving radiance. This database was used in conjunction with guidance from radiative transfer theory to develop best-fit models for the generally unknown shape factors in terms of the known quantities.

A paper (Mobley et al., 2002) describing the background theory and the shape factor models has been submitted. A companion paper showing the application of the shape factor inversion methodology to both synthetic and actual data is in preparation (Lyon et al., 2002).

No field data were acquired in this work. Therefore no data have been submitted to a national data archive.

RESULTS

The IOP-dependent shape factor models can predict the shape factors with accuracies ranging typically from two to 20%. Error analysis suggests that IOP retrievals are primarily influenced by uncertainties in the backscattering shape factor f_b (see Mobley et al., 2002 for the definition of f_b and for its model), rather than by uncertainties in the remaining shape factors and related quantities. Our model for the backscattering shape factor gives predictions that are correct to within 5% for 96% of the synthetic data points used to develop the model. Figure 1 shows our ability to predict the all-important backscatter shape factor.

The question next arises as to how well we can predict the in-air remotely sensed reflectance RSR_a (which is equivalent to the remote-sensing reflectance) using all of the shape factor models. Figure 2 gives the answer: 68% of the RSR_a predictions fall within 10% of the correct (Hydrolight computed) values, and 96% fall within 20% of correct (shown by the dashed lines in Fig. 2); 86% of the predictions are within ±0.0005 sr^{-1} of the correct value. The model-actual correlation coefficient is r = 0.983.

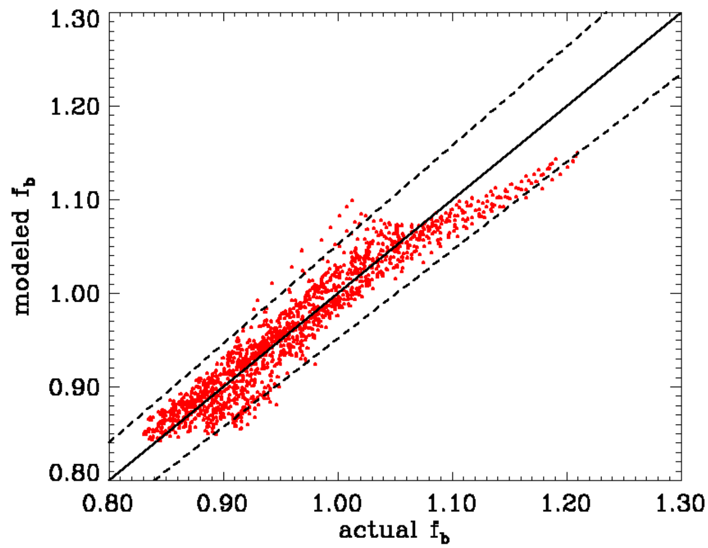

Fig. 1. Comparison of modeled and actual f_b values. 96% of the modeled values lie within the dashed lines, which represent values within 5% of the correct value; the model-actual correlation coefficient is r = 0.955.

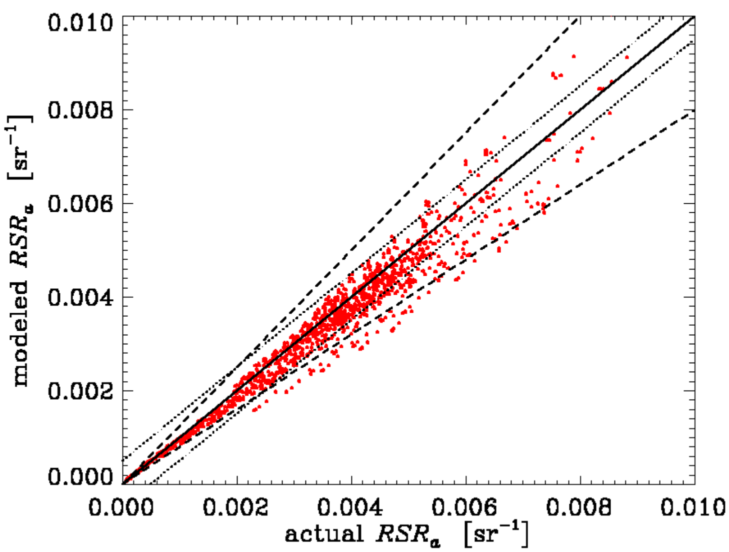

Fig. 2. RSR_a as modeled using the shape factor models. The dashed lines are 20% error bounds; the dotted lines are ±0.0005 sr^{-1}. The model-actual correlation coefficient is r = 0.983.

These results are very encouraging and warrant the continued development of the RTE shape-factor inversion algorithm and its evaluation using both synthetic (Hydrolight generated) and real data obtained at sea.

IMPACT/APPLICATION

The problem of extracting environmental information from remotely sensed ocean color spectra is fundamental to a wide range of basic and applied science problems. No single inversion technique can be expected to be superior in all situations; therefore all techniques must be evaluated. In addition to investigating a new type of inversion, part of our work is to evaluate when the shape factor technique is superior to other techniques, and when it is not. This work thus adds to the existing suite of remote sensing analysis techniques.

TRANSITIONS

The shape factor models and the underlying database have been given to Dr. Frank Hoge of NASA Goddard Space Flight Center, Wallops Flight Facility and Dr. Paul Lyon of EG&G, who are using the database and the shape factor models to simulate retrievals of water IOPs from measured water-leaving radiances.

RELATED PROJECTS

Dr. Frank Hoge of NASA is separately funded by NASA for his work on development and evaluation of the shape factor inversion technique. NASA also provided funding for the work described here via an interagency transfer.

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